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THE PRECISE SETTING OF THE POSITION INDICATORS ON
THE PARKES 210-FT RADIO TELESCOPE

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Summary

These notes give techniques developed for the precise setting of the dials which indicate the position of the telescope; that is, the zenith angle and azimuth dials giving the position of the dish in altazimuth coordinates and the hour angle and declination dials giving the position of the master equatorial in equatorial coordinates, together with the meters indicating any misalignment between the master equatorial mirror and the dish axis. In addition to the precise setting of these dials and correct alignment of the optical axis of the error detector with the dish axis, four other pieces of information can be obtained:

- (1) The differential sag in the master equatorial mirror when rotated about the polar axis, at declination -90° .
- (2) The angular displacement, in the azimuth direction, of the mirror to the polar axis.
- (3) A measurement of the irregularities in the azimuth track from the mean plane of the track.
- (4) The telescope latitude (or angle between the telescope azimuth axis and the master equatorial polar axis) which is necessary in converting from the altazimuth into equatorial coordinates and vice versa.

In addition, a comparison of declination and zenith angle scales, along the north-south meridian, has been made.

1. INTRODUCTION

The system for pointing the 210-ft Radio Telescope at Parkes consists of a master equatorial unit, mounted on separate foundations and situated at the intersection of the azimuth and altitude axes of the dish; an error detector unit, attached to the hub of the telescope, which measures the angular deviation of the dish axis from the master equatorial direction and provides signals to servo the dish so as to keep the angular deviation small.

The master equatorial unit is a precision made equatorially mounted instrument which carries a flat mirror 3.25 in. diameter, at a radius of 23.5 in. from the intersection of its axes. It can be pointed in any desired direction in equatorial coordinates (declination and hour angle). Motions in declination and hour angle are each achieved with a worm and wheel, with a 360:1 reduction. Angles are measured from the rotation of the worm (1 turn = 1°).

The error detector is an optical device, with photo-cells, arranged to resolve the angular displacement of its optical axis from the normal to the mirror, into two components, one in a plane containing the direction in which the dish tips and the other in a plane at right angles to this. These displacement angles are displayed on meters, calibrated in minutes of arc.

These notes indicate the methods used in precise settings of the dials on the master equatorial (declination and hour angle) and on the dish (zenith angle and azimuth) and the method used to align the optical axis of the error detector, making a total of six inter-related angles. It is assumed that the master equatorial unit has its polar axis

correctly aligned to the South Celestial Pole, since all dials are set with reference to this axis. This alignment is basic to this telescope, and is carried out by optical observations of stars around the South Celestial Pole. It is also assumed that the declination axis has been adjusted to be exactly 90° to the polar axis.

2. SOME DEFINITIONS

Before describing the techniques involved it is desirable to define precisely the quantities measured by the dials.

2.1 Declination (δ) is the angle between the mirror normal and a plane at right angles to the polar axis. It is positive to the north and negative to the south and is -90° when the mirror normal is parallel with the polar axis and pointing South. (The declination scale is set at this condition.)

2.2 Zenith Direction and Meridian Plane. This is the direction "vertically" upwards. We must distinguish between three possible directions, as follows:

- (1) The direction of local gravity - as defined by a bubble or a mercury pool. This is known as the Local Astronomical Zenith (or Geographic Zenith).
- (2) The direction of the center of the earth; which gives the Geocentric Zenith.
- (3) The direction of the azimuth axis about which the telescope rotates; this gives the Telescope Zenith.

Associated with each of these directions is a meridian plane, which contains the polar axis and the given direction. We thus have three planes which are close to each other:

- (1) Local Astronomical Meridian Plane
- (2) Local Geocentric Meridian Plane
- (3) Telescope Meridian Plane.

Each of these planes can be used to define the "zero" hour angle plane. In setting up the zero of the master-equatorial hour-angle scale, the Telescope Meridian Plane has been used because this plane can be readily established and re-established if necessary. If there are no local gravitation anomalies, planes 1 and 2 are coincidental. Plane 3 was intended to be coincidental with plane 1, but due to manufacturing inaccuracies, and a possible subsequent uneven sagging of the azimuth track, the two planes are now a small angle apart. (This, of course, in no way affects the pointing accuracy of the telescope.)

2.3 Hour Angle (h). This is the angle (expressed in hours, minutes and seconds of angle by the transform 1 hour = 15°) between the Telescope Meridian Plane (as defined above) and a plane through the polar axis containing the direction to be specified.

2.4 Azimuth Axis, Azimuth Plane and Azimuth Angle (Λ). The azimuth axis is that axis about which the telescope rotates by motion around the azimuth track. The azimuth plane is at right angles to the azimuth axis and is the mean plane of the azimuth track. The azimuth angle (symbol Λ) is the angle, in the azimuth plane, of the projection into the plane of the direction to be specified. Zero azimuth is defined as the direction of the intersection of the Telescope Meridian Plane with the azimuth plane, taken in the northern direction. It should be noted that azimuth is measured in the mean plane of the track and not in the local Astronomical (horizontal) plane.

2.5 Zenith Angle (z) is the angle between the dish axis and the azimuth axis. Zero zenith angle is when the dish axis is along the azimuth axis.

2.6 Sidereal Time. Associated with each meridian plane is a sidereal time, which is the Right Ascension of the stars in the meridian plane at that instant. We can thus have a local astronomical sidereal time, associated with planes 1 and 2 (assuming coincidence) and a telescope sidereal time which will differ slightly from each other (by up to several seconds). The astronomical sidereal time at Parkes is $9^{\text{h}}53^{\text{m}}04^{\text{s}}$ ahead of the meridian plane through Greenwich, whereas the telescope sidereal time is $9^{\text{h}}53^{\text{m}}00^{\text{s}}$ ahead of Greenwich.

2.7 Latitude (ϕ). This is the declination of the zenith direction; again there are three latitudes, one for each zenith direction. At Parkes we have:-

ϕ	= Astronomical or Geographic Latitude	= $-32^{\circ}59'.9$
ϕ'	= Geocentric Latitude	= $-32^{\circ}49'.3$
ϕ''	= Telescope Latitude	= $-33^{\circ}00'.0$

It is this latter value of ϕ'' which should be used in converting from altazimuth coordinates into equatorial coordinates and vice versa. (Appendix I gives the conversion formulae.)

2.8 Pointing Error. This is the angle between the normal to the master equatorial mirror and the optical axis of the error detector. This error is a vector quantity and is resolved (in the error detector) into two components, namely the zenith-angle component and the azimuth component.

The zenith angle component is resolved into a plane containing the azimuth axis in the direction of Rib 1 of the dish (i.e. the direction of tilting). The other component is at right angles to this, the signs being as given in Figure 1.

A positive zenith-angle component of pointing error is in the direction of Rib 1 when the optical axis of the error detector has a greater zenith angle than that of the

master equatorial mirror. A positive azimuth component of error is when the error detector axis is 90° clockwise (i.e. to the right) of the master equatorial mirror, when viewed from above, i.e. when the error detector has a greater azimuth component than the master equatorial mirror.

To bring the pointing error to zero, changes in zenith angle Δz and azimuth ΔA are as follows:-

Δz = Zenith angle component of pointing error.

ΔA = Azimuth component of pointing error $\times \operatorname{cosec} z$.

It should be noted that there is no requirement for the azimuth track to be geographically horizontal; the telescope would still perform precisely, in both equatorial and altazimuth coordinates if the track were tipped say at 10° to the horizontal, provided that the above definitions of zenith angle and azimuth are used.

3. ROUGH SETTING OF DIALS

The dials can be set very close to their correct positions (say to within $\pm 1'$) as follows:

The master equatorial is taken to the vertical position, and a spirit-level is placed on top of the mirror. The master equatorial is shifted in declination and hour angle in turn until the level is central in all positions. The declination scale is then set to the geographical latitude of Parkes ($-32^\circ 59'.9$) and the hour angle to $00^h 00^m 00^s$. The telescope is turned to orient Fib 1 along the north-south survey line, as determined by a theodolite. The azimuth scale is then set to $000^\circ 00'$. Similarly the zenith-angle scale is set to zero when the geometrical axis is vertical as determined by theodolite survey. With the telescope at the zenith, as determined above, and with $A = 000^\circ 00'$ and the master equatorial at $\delta = -32^\circ 59'.9$, $h = 00^h 00^m 00^s$ the error detector box is moved by its adjusting screws to give zero components of zenith angle error and azimuth error.

4. ROTATION OF MASTER EQUATORIAL ABOUT THE POLAR AXIS

This test has as its objects:

- (1) The precise setting of the declination scale (at $-90^{\circ}00'.0$).
- (2) Measurement of any differential sag in the polar axis as the master equatorial is rotated.
- (3) Measurement of the angular offset of the mirror, in the direction of azimuth component of pointing error.

On a windless day, the telescope is taken to $z = 57^{\circ}00'$ at azimuth 180° (i.e. the dish pointing to the South Celestial Pole). The telescope is then locked in this position by putting the brakes on. The master equatorial is taken to declination -90° and hour angle to 12^h ; the hour angle is rotated clockwise (at $60^{\circ}/\text{min}$) through a full 24 hours (i.e. 360°), and the readings of zenith angle and azimuth components of pointing error read on the error meters every half hour of rotation, and plotted as shown in Figure 2.

If the mirror is exactly on the polar axis and there is no differential sag in the polar axis, constant error readings are obtained, independent of the hour angle. If the errors are too large, the dish can be shifted in zenith angle and azimuth to reduce them. The readings on the azimuth and zenith angle dials at this stage are approximate only and are not important to this test.

In general, the locus of the errors will be a circle the radius of which is a measure of the mirror offset from the polar axis. This has two components. One due to the declination not being exactly $90^{\circ}00'.0$ and the other due to the fact that the mirror normal is not at right angles to the polar axis in the azimuth plane. By successively changing the declination by amounts calculated from the error plots, the circle resulting from rotation can be made small (radius of the order of 0.1 minute of arc).

Figure 3 shows such a plot, which is the residual after several adjustments of the declination. It will be seen that the "circle" is quite distorted, being somewhat flattened by differential sag and also having a re-entrant loop. The mirror has a small offset of something less than 0.1' in the azimuth direction. At this stage, the declination scale is re-set to $-90^{\circ}00'.0$, and should be correct to something better than 0.1'. (If necessary, the mirror can be re-adjusted in the "azimuth" direction to make it at right angles to the polar axis.) The declination scale should then be correct over all its range.

At present it is believed that the master equatorial mirror is at right angles to the azimuth axis, the error in the declination scale and the differential sag in the polar axis are all approximately equal to 0.05'.

5. ROTATION OF THE DISH ABOUT THE AZIMUTH AXIS

The purpose of this test is to:

- (1) Set the zero of the hour angle scale.
- (2) Set the error detector unit so that its optical axis is aligned to the dish axis of the telescope (with the dish at the zenith).
- (3) Measure the telescope latitude.
- (4) Measure any irregularities in the azimuth track.
- (5) Set the zero of the zenith angle scale.

Both the dish and the master equatorial are taken to the zenith, the master equatorial being set on $-32^{\circ}59'.9$ (the geographic latitude of Parkes) and $h = 00^{\circ}00'00''$ as previously set with a spirit level. The dish is set at $z = 00^{\circ}00'.0$, i.e. with its geometrical axis vertical as determined with a theodolite.

The dish is then rotated a full 360° about its azimuth axis at $20^{\circ}/\text{min}$. At every 5° (or 10°) the readings of azimuth and zenith angle components of error are read. The

dish is then taken back at the same speed and the readings repeated, and an average determined. A "zenith plot" is then prepared. This is a plot of the zenith region immediately above the normal to the master equatorial mirror, in declination and hour angle coordinates (to the same scale). A large scale of ± 1 minute of arc is used. For each direction of Rib 1 of the dish, the zenith angle component of error is marked in that direction, with appropriate sign. The azimuth component of error is then marked at right angles, signs being as shown in Figure 1. (See Figure 4 for method of plotting position of optical axis for each value of azimuth)

This is done for all values of azimuth, and a locus of the error detector optical axis drawn. (See Figure 5) This should ideally be a circle, centered on the azimuth axis. After several adjustments of the mirror position, the estimated center of the circle so obtained can be made coincident with the master equatorial mirror position. This test is done with a circle radius of approximately 1 minute of arc. If necessary, this can be adjusted by altering the zenith angle of the telescope slightly. When the estimated center of the circle is on the mirror position, the hour angle scale is set to $00^h 00^m 00^s$. The declination reading is then the telescope latitude. Any misalignment of the error-detector optical axis with the azimuth axis is shown by an azimuth component of error with the dish at zero azimuth. This misalignment can be reduced to zero by shifting the error detector in the azimuth direction.

Figure 6 shows a zenith plot for the Parkes Radio Telescope. It will be seen that the center of the locus is coincident with the mirror position. The telescope was tilted $0'.75$ and it will be seen that there is a residual component of azimuth error of $-0'.3$ which could be reduced by shifting the error detector by azimuth adjustment.

It will also be seen that the locus is not a perfect circle, but has irregularities which result from variations in the azimuth track. Figure 7 shows the component

irregularities in the zenith-angle direction and also in the azimuth direction. The irregularities between 0 and 180° are identical (but reversed in sign) to those occurring between 180 and 360°. These are shown by the dotted curves in Figure 7. The agreement is very close, indicating that the irregularities must result from the track surface. An attempt was made to correlate these irregularities with track joints, but none could be found. (See Figure 8 for plan of track showing joints in track and position of rollers at zero azimuth.)

It should be noted that the irregularities depend on the average level of the four rollers on the track and are not variations in the track itself at the azimuth angles given.

The radius of the locus circle gives the angle between the master-equatorial optical axis and the azimuth axis. This should be the reading on the zenith-angle dial. It is not possible to get a unique combination of the position of the geometrical axis of the dish and hub and the zenith angle position of the error detector, so it is necessary to set the geometrical axis of the dish to the vertical with a theodolite, and then adjust the optical axis of the error detector to bring the zenith angle component of error to zero.

6. SETTING OF ZERO OF AZIMUTH SCALE

After the error detector axes have been lined up with the azimuth axis, the zero of the azimuth dial can be reset exactly to zero. This is done by taking the dish to 45° zenith angle, the master equatorial to the corresponding declination on the northern meridian ($h = 00^h 00^m 00^s$) and shifting the azimuth until the azimuth component of error is brought to zero. The dial is then set to 000°00'.0. This alignment can be done at any zenith angle, but 45° has been chosen since it minimizes the effects of the altitude axis not being parallel to the plane of the azimuth track.

This can be checked by measuring the azimuth component of error when the telescope is moved down the northern meridian, under equatorial control in zenith angle, but with the azimuth brakes on. This error is small (less than 0.1'). A check on the azimuth scale at 180° can be made by repeating the test along the southern meridian.

7. COMPARISON OF ZENITH ANGLE AND AZIMUTH SCALES

By bringing the telescope down the northern and southern meridians under equatorial control, the declination can be noted at various zenith angles. This is best achieved by taking an automatic printout of declination when the zenith angle passes through cardinal points say 5° apart. A plot of zenith angle versus declination can then be drawn. This is shown in Figure 9, which has been drawn for $\delta = 33^{\circ}00'.0$ at $z = 60^{\circ}$.

As the zenith angle is reduced, there is a difference of approximately 0.1' per 6° of zenith angle. This is thought to be due to elastic flexing of the hub structure and gears. The zenith angle is measured on the altitude gearbox, and as the dish tilts, the flexing of the structure causes the hub axis (and therefore the error-detector optical axis) to have a greater ZA than that for a perfectly rigid structure. This difference includes any sag in the optical axis of the error detector. At present in the Parkes Telescope, this sag has been set to be zero, and measurements of deflections of the error-detector unit show this to be substantially true.

APPENDIX I

Relations between altazimuth and equatorial coordinates

z = Zenith Angle

A = Azimuth Angle

δ = Declination Angle

h = Hour Angle

ϕ'' = Telescope latitude $(-33^{\circ} 00'.0)$

Equatorial to altazimuth conversion

$$\sin z \sin A = -\cos \delta \sin h$$

$$\sin z \cos A = \sin \delta \cos \phi'' - \cos \delta \cos h \sin \phi''$$

$$\cos z = \sin \delta \sin \phi'' + \cos \delta \cos h \cos \phi''.$$

Altazimuth to equatorial conversion

$$\cos \delta \sin h = -\sin z \sin A$$

$$\cos \delta \cos h = \cos z \cos \phi'' - \sin z \cos A \sin \phi''$$

$$\sin \delta = \cos z \sin \phi'' + \sin z \cos A \cos \phi''$$

8. ACKNOWLEDGEMENT

The techniques described in this report were developed during the adjustment of the Parkes telescope and have been used to measure certain of the pointing errors as part of a performance study supported by NASA Research Grant NsG-240-62 to the Radiophysics Laboratory.

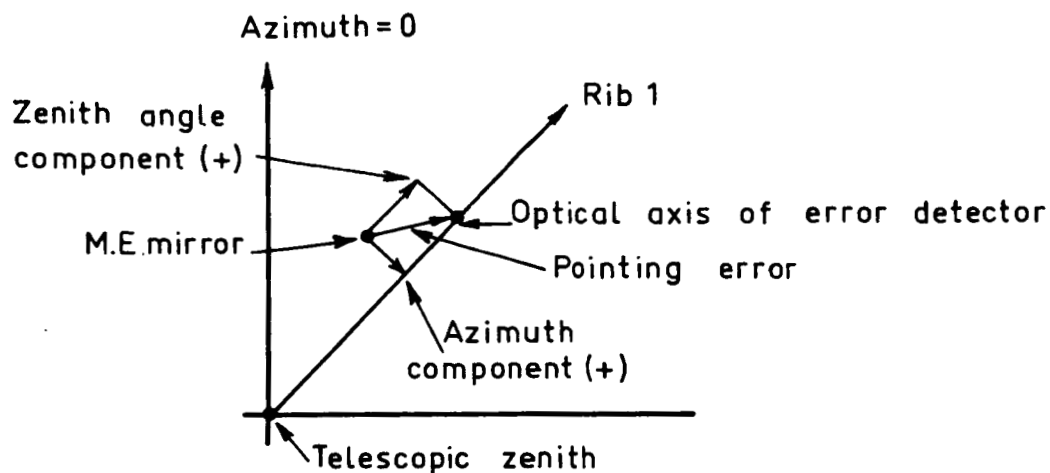


FIG.1 Sign of components of pointing error

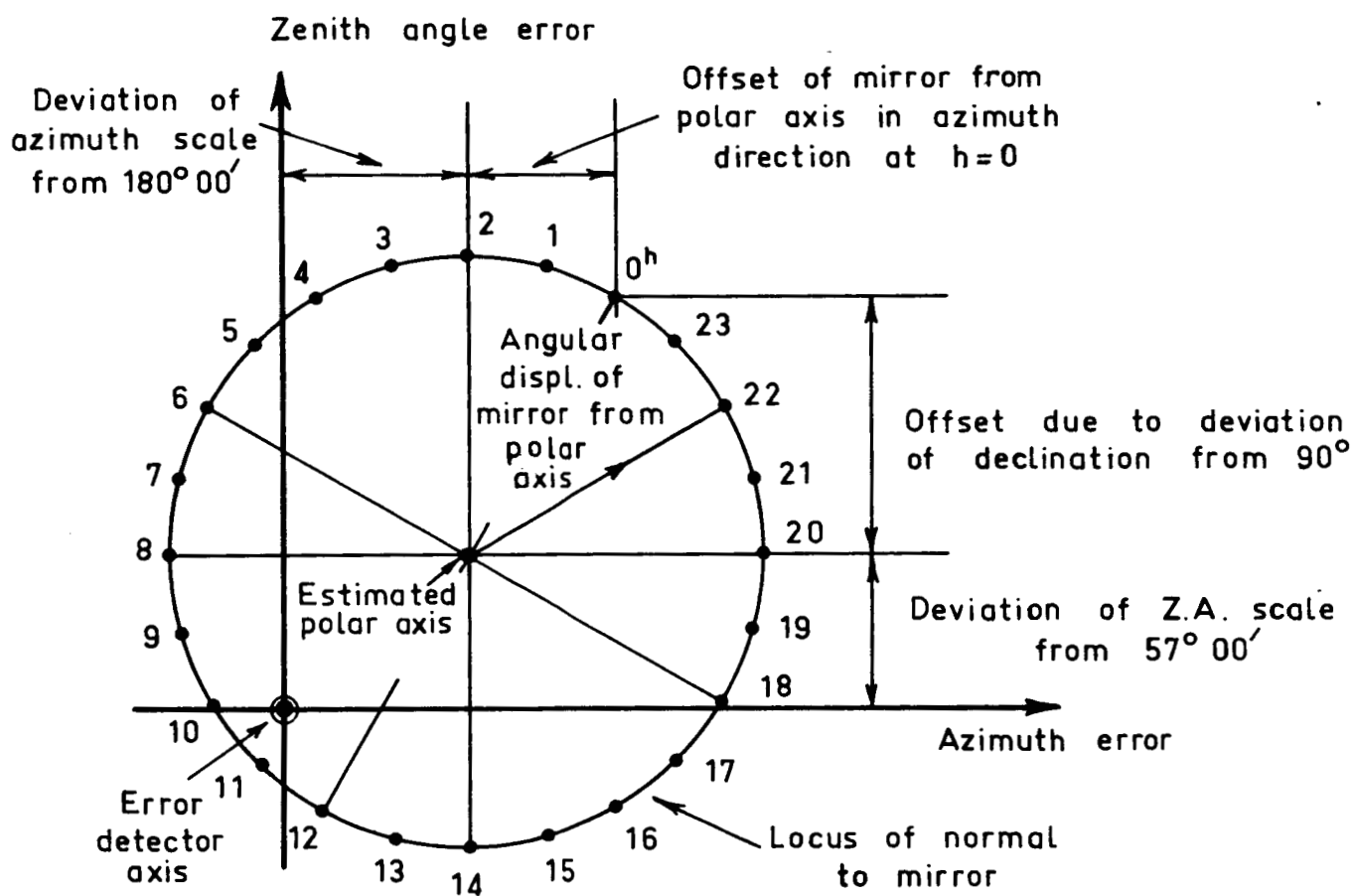


FIG.2 Variation of error components with hour angle when pointing to South celestial pole

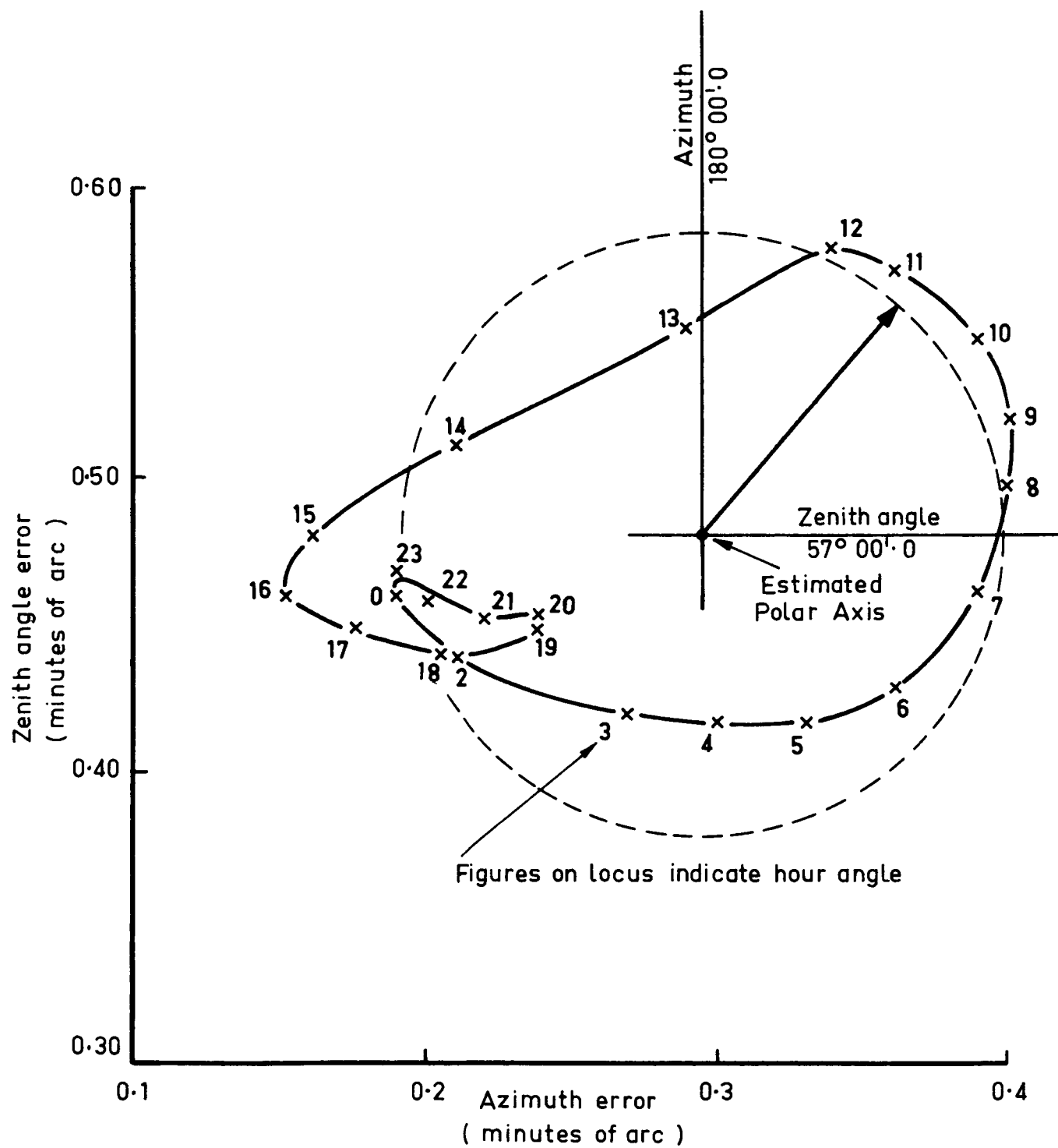


FIG. 3 Variation of error components with hour angle

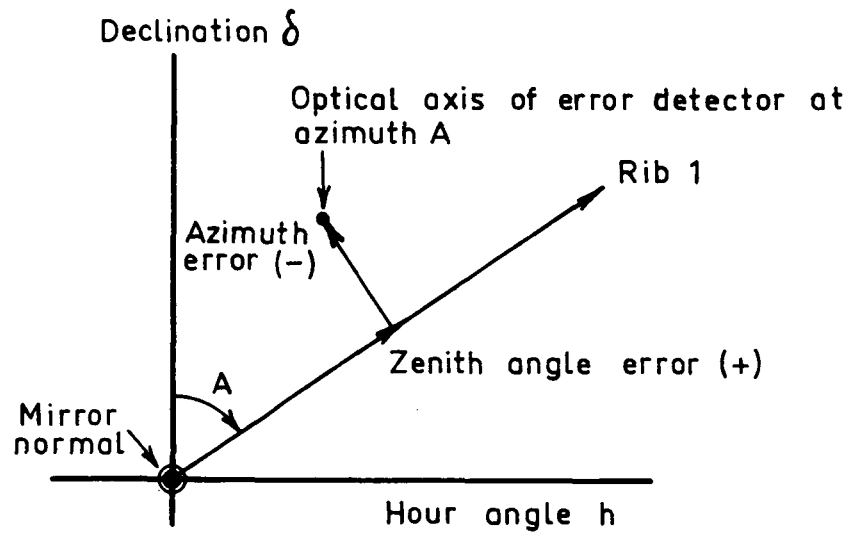


FIG 4 Determination of position of optical axis of error detector at azimuth A

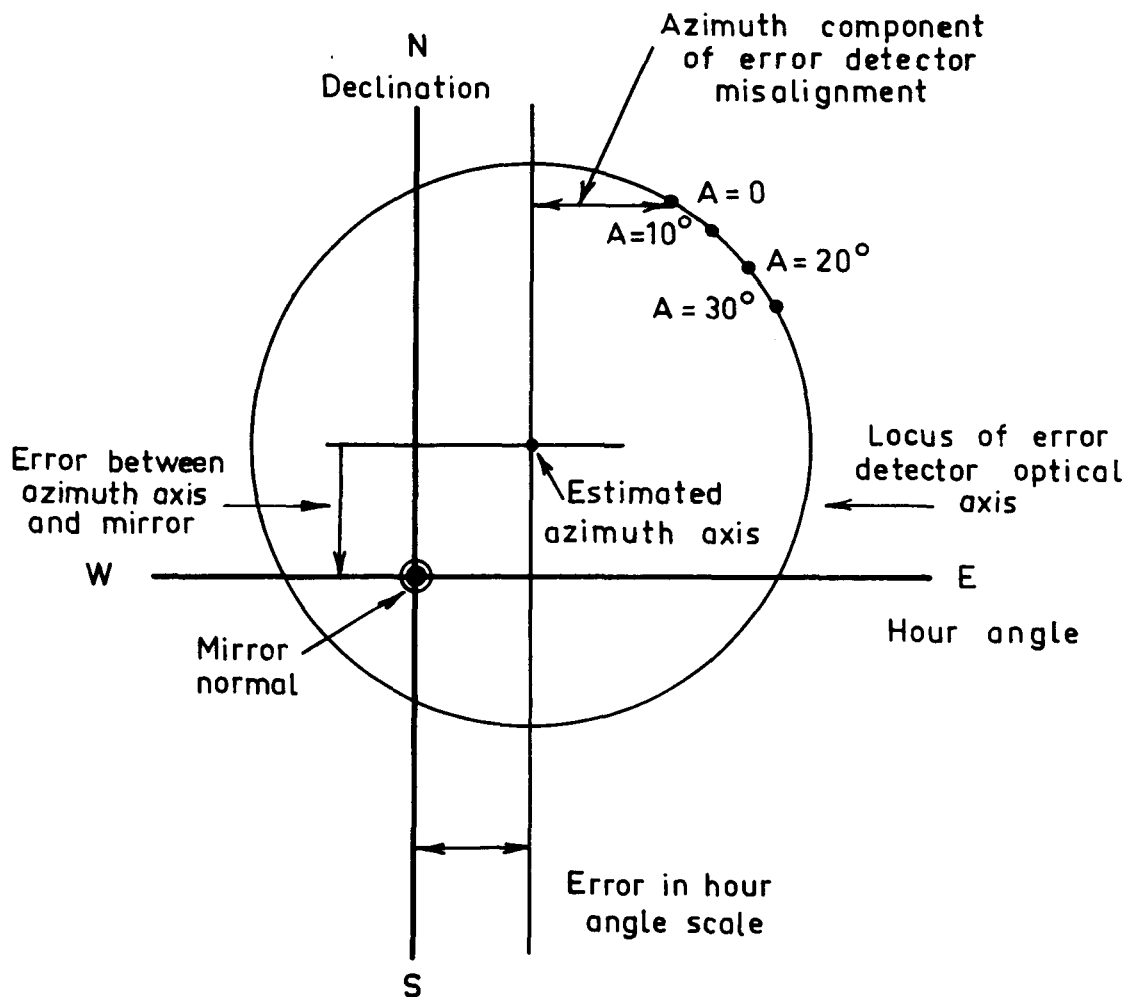


FIG 5 Variation of error components with azimuth when pointing at zenith

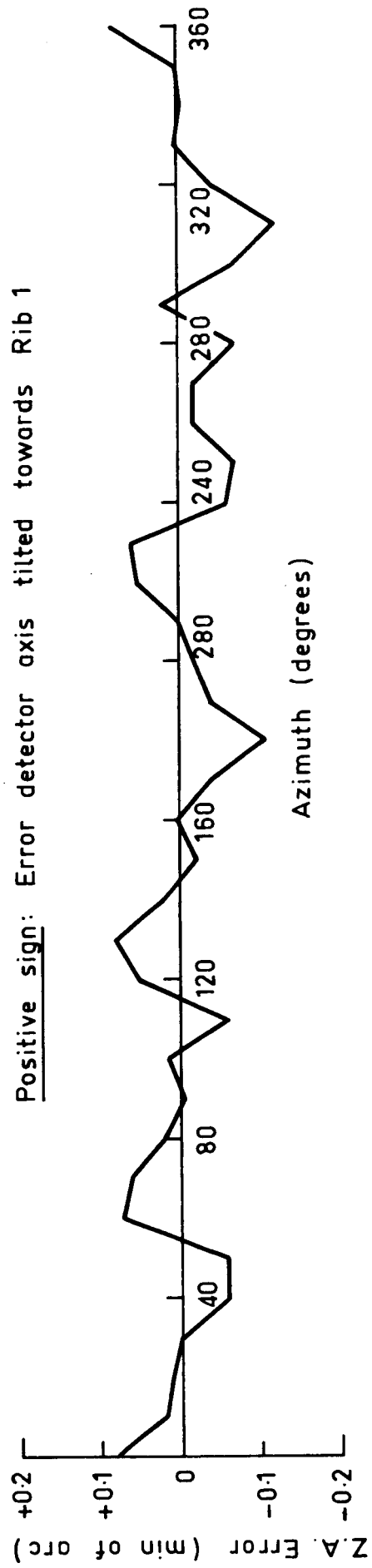
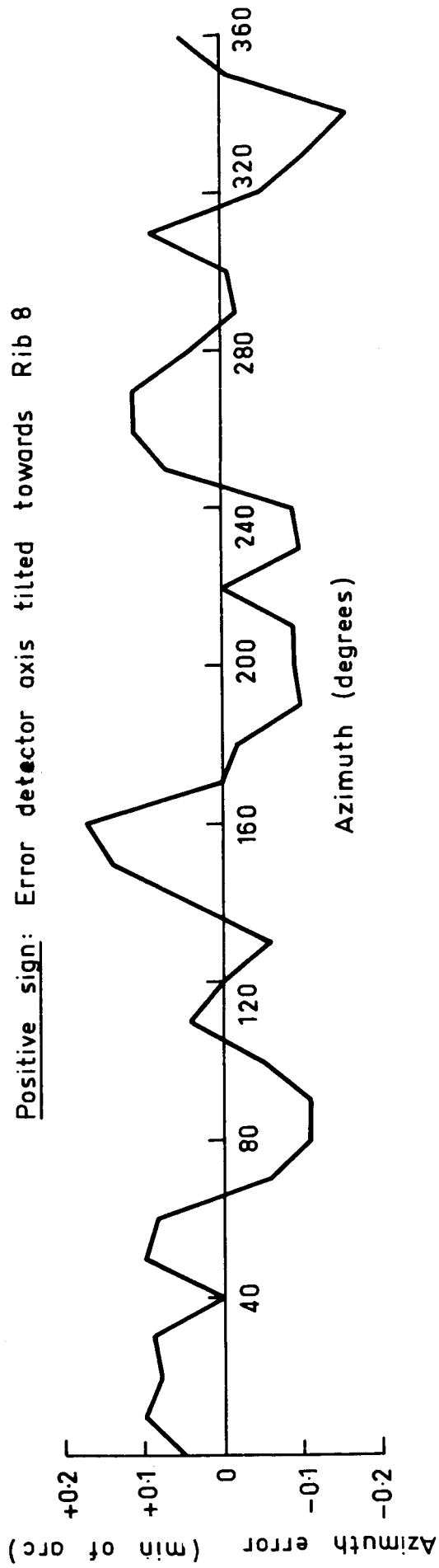


FIG 7 Variation of track irregularities with azimuth

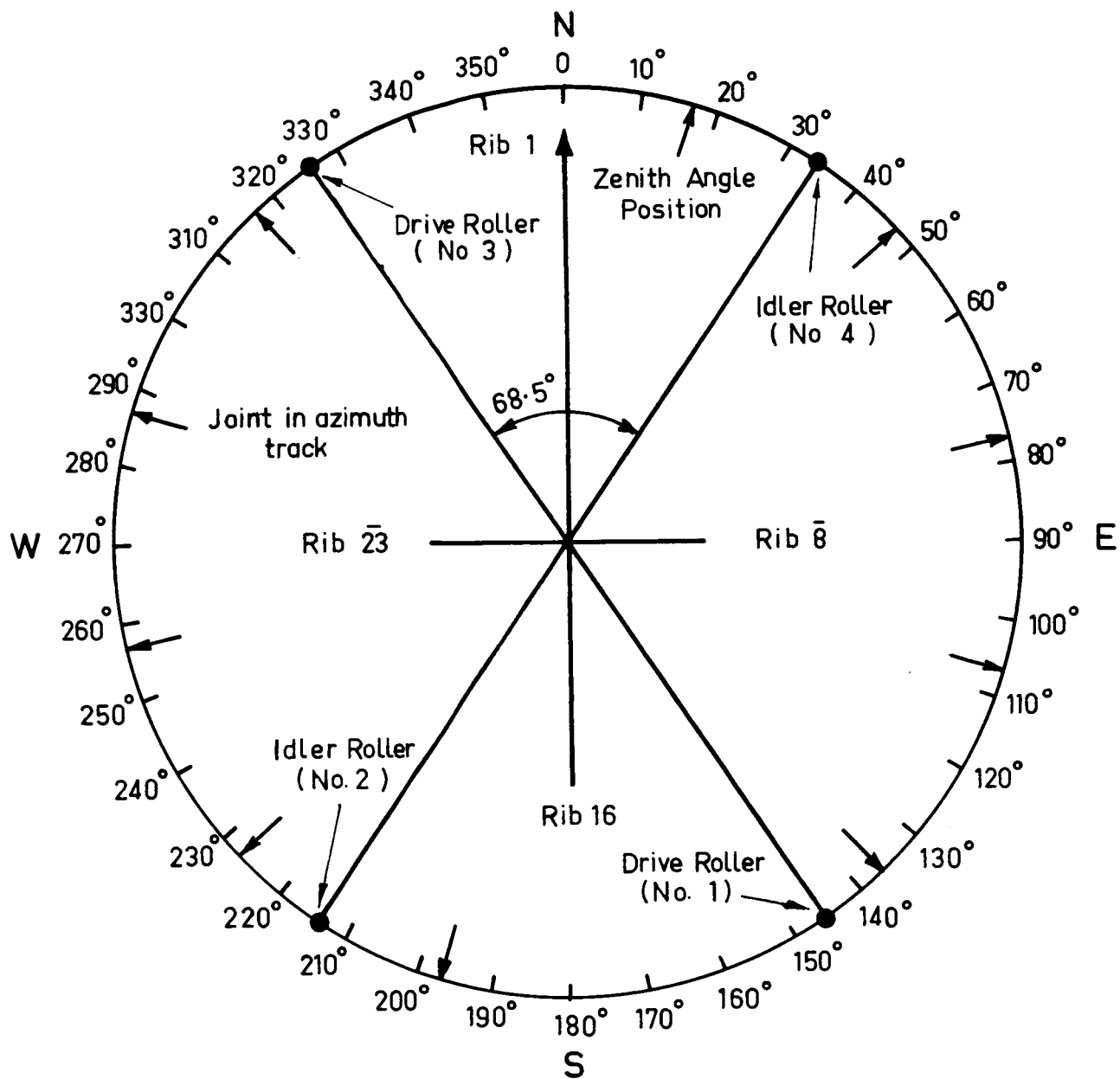


FIG 8 Azimuth angles of track joints and roller positions at zero azimuth.

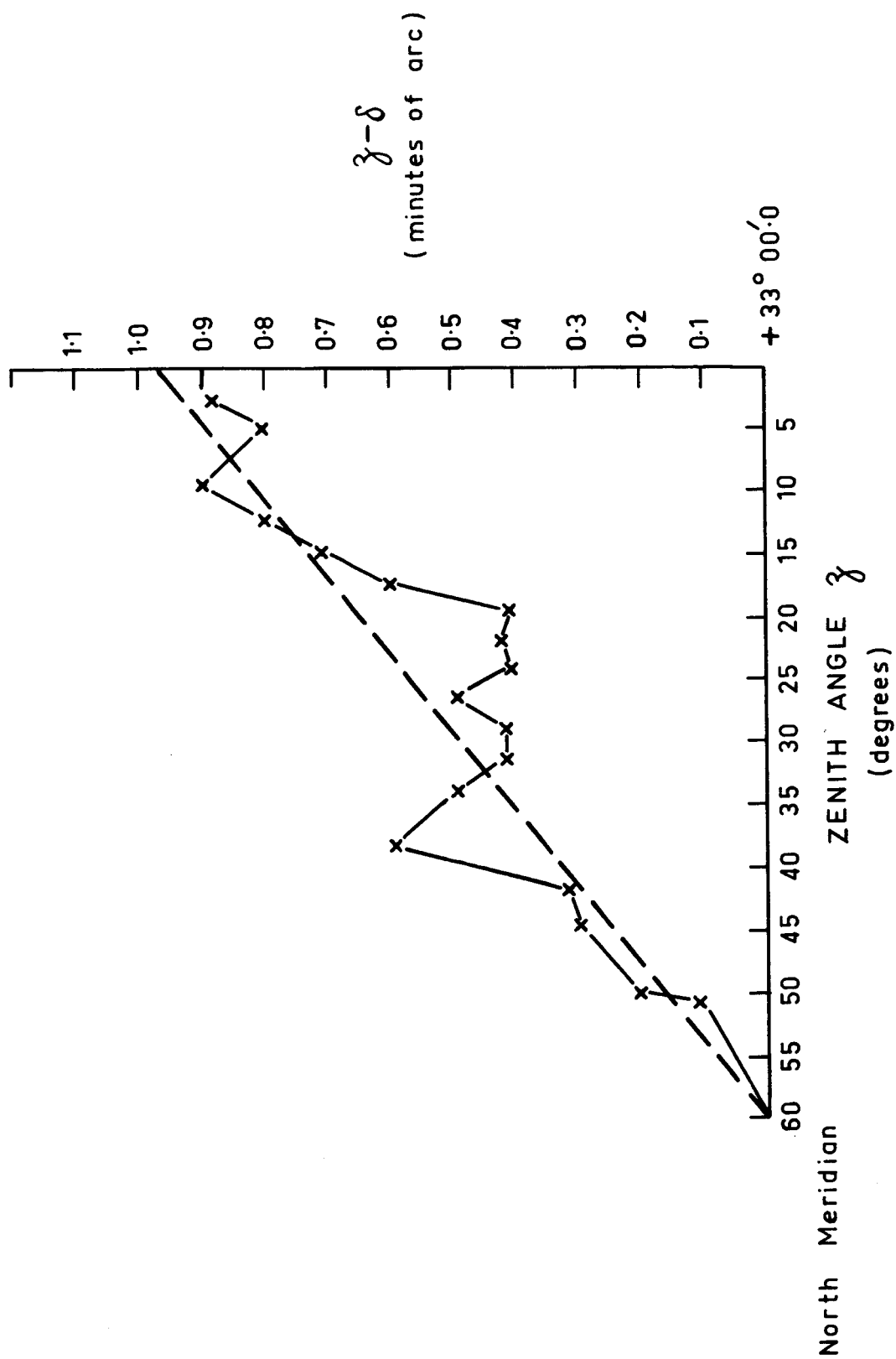


FIG. 9 Variation of $z-\delta$ with change of z